Modeling and Analyzing the Propagation from Environmental through Sonar Performance Prediction

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LONG-TERM GOALS

Central to the long-term goals of this joint project is to understand the physics of the propagation of uncertainty through the interfaces between oceanography, acoustics, array processing and performance prediction. Our specific emphasis is on addressing the issues relevant to and communicating results to the operational naval sonar operator. We will develop an efficient overall simulation platform that combines all of the components of the baseline (mean) and uncertainty problem. The development of a methodology to distill the complexity and uncertainty of the ocean acoustic environment and the system level sensitivities to relevant situational awareness for the operator is an important goal of this research.

OBJECTIVES

The objective of this research program is to develop a systematic approach to addressing the catastrophic deficiencies in sonar performance prediction in the littoral environment. Sorting out the issues of uncertainty, bias and variability is critical. It is a primary objective to develop an approach, which, for a given scenario, determines which environmental parameters (bathymetry, geo-acoustics, sound speed profile, internal waves) drive the uncertainty in acoustic propagation. Determination of the most sensitive environmental parameter will lead to understanding of the measurement requirements as well as the fundamental limitations on accurate acoustic performance prediction.

APPROACH

Work at ORINCON for the past year has focused on two related areas. The first involves analysis of the system issues associated with acoustic modeling and sensitivity to the environmental uncertainty in the sonar performance prediction system. The second area of research has been in the use of rapid geo-acoustic characterization and the development of an approach to estimate the environment as well as determine sonar performance sensitivity to the uncertainties in our environmental knowledge.

SYSTEM ISSUES:
Tactical Decision Aids (TDAs) are computer applications that perform acoustic model-based performance predictions based on available inputs and data bases, manipulate the sonar equation, display the results usually in very attractive (and convincing) color graphics, and provide advice or information to the operators. They are becoming increasingly sophisticated. Is the advice provided good? Are results presented correct in some absolute sense? To what extent would an expert believe the TDAs? Trust them? How should operators use them?

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The importance of input errors can be understood by examining the sensitivity of the output to those errors. A SENSITIVITY measure is needed. There are two types of concerns about inputs: BIAS and VARIABILITY. By BIAS I mean that the inputs such as bottom properties for a given area are wrong in some average sense. There are a growing number of examples in which shallow water predictions differ from measurements by many dB. The data bases themselves need some quality assessment. E.G. Very few measurements, user beware. Lots of measurements, models and data agree to within XX dB over the frequency range YY to ZZ. This is a goodness of fit criterion. The user needs to be told whether there is low or high confidence in the prediction. This involves both quality of the inputs and sensitivity to those inputs.

With regard to TDAs, we need to ask how they convey uncertainty, sensitivity and confidence to the user. We also need to be warned when tactical advice is very sensitive to parameters about which there is uncertainty. We need to face up to the reality of faulty inputs and uncertainty, rather than proceeding with an idealized problem as if the inputs were perfect. The target source level, aspect dependence, depth etc are well within the realm of the operator to deal with. Acoustic propagation on the other hand is something for which he needs help from the technical community. We should not opt out by saying, for example, that environmental uncertainty is not important because we do not know the target source level.

ESTIMATING UNCERTAINTY:
In order to estimate uncertainty, sensitivity and bias in a relevant manor for the sonar operator, we need to develop a structural approach to determining factors in the environment that drive the uncertainty of acoustic performance prediction. To this end we have focused on an approach for performing geo-acoustic inversions from passing surface ships of opportunity. This approach, matches a set of basic acoustic observables (time-spread, striation spacing, slope of the TL with range), to a set of synthetic propagation model runs, yielding a sediment type that is consistent. By estimating an effective sediment we can perform two very important functions. Primarily we can reduce the error (BIAS) of the acoustic propagation modeling by as much as 20 or 30 dB at long ranges in shallow water. After this BIAS has been accounted for by updating the geo-acoustic sediment, we can estimate the uncertainty in acoustic forward modeling (Transmission Loss) via the analysis of variance of the geo-acoustic characterization process. The shape of the final cost function will reveal whether a particular environment has a well characterized sediment (and therefore small uncertainty in acoustic propagation modeling) or a very poorly constrained inversion (and therefore a large uncertainty.

We are examining a structured approach to validating TDA's through a combination of taking tactical data, performing predictions using TDAs and performing acoustic measurements to examine errors, sensitivities and variability – leading us to a measure of confidence in the TDA as well as a data driven bound on the UNCERTAINTY.

WORK COMPLETED

Work this year consisted of interaction with Navy Sponsors at various levels to ascertain the nature of the system and systematic problem. Analysis of these issues led to the presentation by Dr. Cox at the Uncertainty yearly review meeting. Dr. Cox also chaired a session on Acoustic Modeling at the Scientific Issues meeting of the Uncertainty Program. Dr. Heaney explored the utility of using the Rapid Geoacoustic Characterization to greatly reduce the BIAS of the prediction and as a basis for quantifying uncertainty in sonar operator relevant terms.

RESULTS

By using in-situ, through the sensor approaches to environmental characterization, the inversion is most likely to be driven by propagation physics that is directly relevant to sonar performance prediction. By measuring the striation slope, the frequency spacing and band averaged TL vs. range of a passing surface ship; it is possible to perform a real-time geoacoustic characterization of the environment. (These Acoustic Observables are compared with a forward model prediction from a set of simplified geo-acoustic parameter sets to find the optimal match.) The results of this inversion are shown in figure 1.

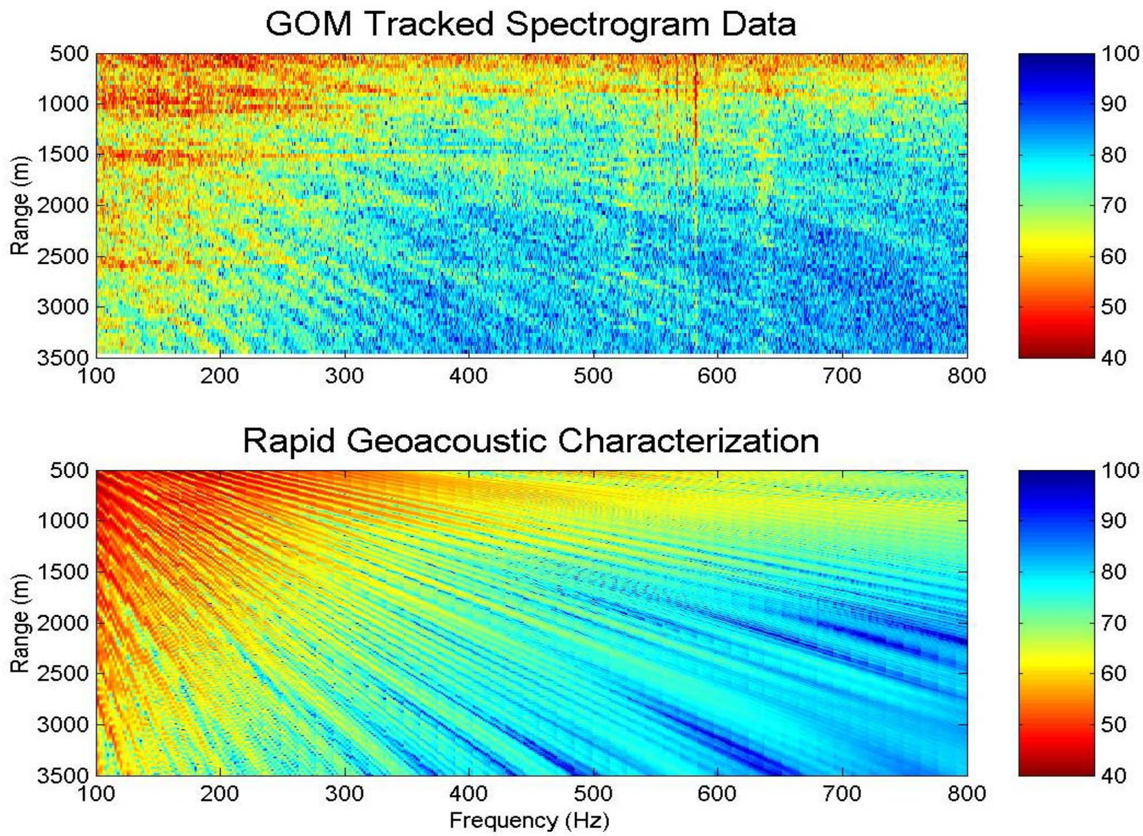

Figure 1. RGC Inversion from Passing Surface Ship

The cost function for the above RGC Inversion is shown in Figure #2. Providing a better estimate of the sediment is not a primary objective of the uncertainty program. It is, in some sense, a pre-requisite to estimating uncertainty. There is no point in determining a 3-5 dB uncertainty in values that are off by 20-30 dB. Once the BIAS has been accounted for, however, it is quite useful to determine the uncertainty in acoustic propagation, in particular, with respect to the geo-acoustic profile. Effectively what is needed is a sensitivity to the geo-acoustic environment. The cost function shown in Fig. 2, contains much of the information we are after.

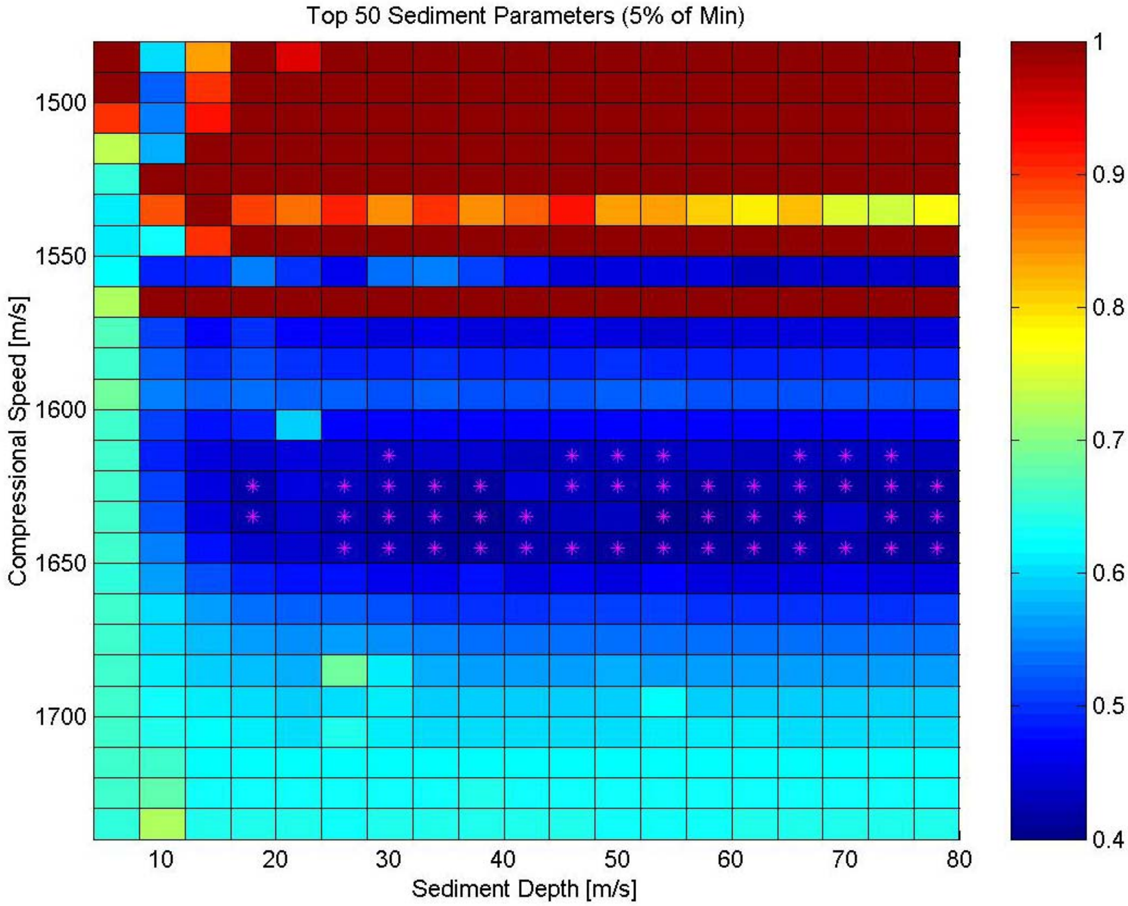

Figure 2. Rapid Geo-Acoustic Characterization Cost Function (with * at the top 50 points).

The Cost Function values within 5% of the minimum are shown with * in Fig. 2. This indicates that the inversion is sensitive to the critical angle (or Compressional Speed at the interface) but is not sensitive to the Sediment Depth. We can utilize the variability of the RGC estimate to determine the variability in propagation (TL) for this particular environment. We take each geo-acoustic profile within 5% of the best Energy, and compute the TL for a set of ranges and frequencies. The variability in this TL is a strong indication in the uncertainty due to geo-acoustic uncertainty. We have not addressed the variability of the geo-acoustic field, nor the uncertainty associated with sound speed variability, internal waves or wind-speed. Note that this particular example is for a downward refracting environment with the sound maximum at the surface and minimum at the sea-floor. With at compressional speed of 1630, the critical angle is near 32 degrees and the propagation is dominated by SRBR (Surface Reflecting – Bottom Reflecting) ray-paths or modes. These paths are insensitive to the details of the sound speed field.

The results of the ensemble of best estimates are shown in Fig. 3.

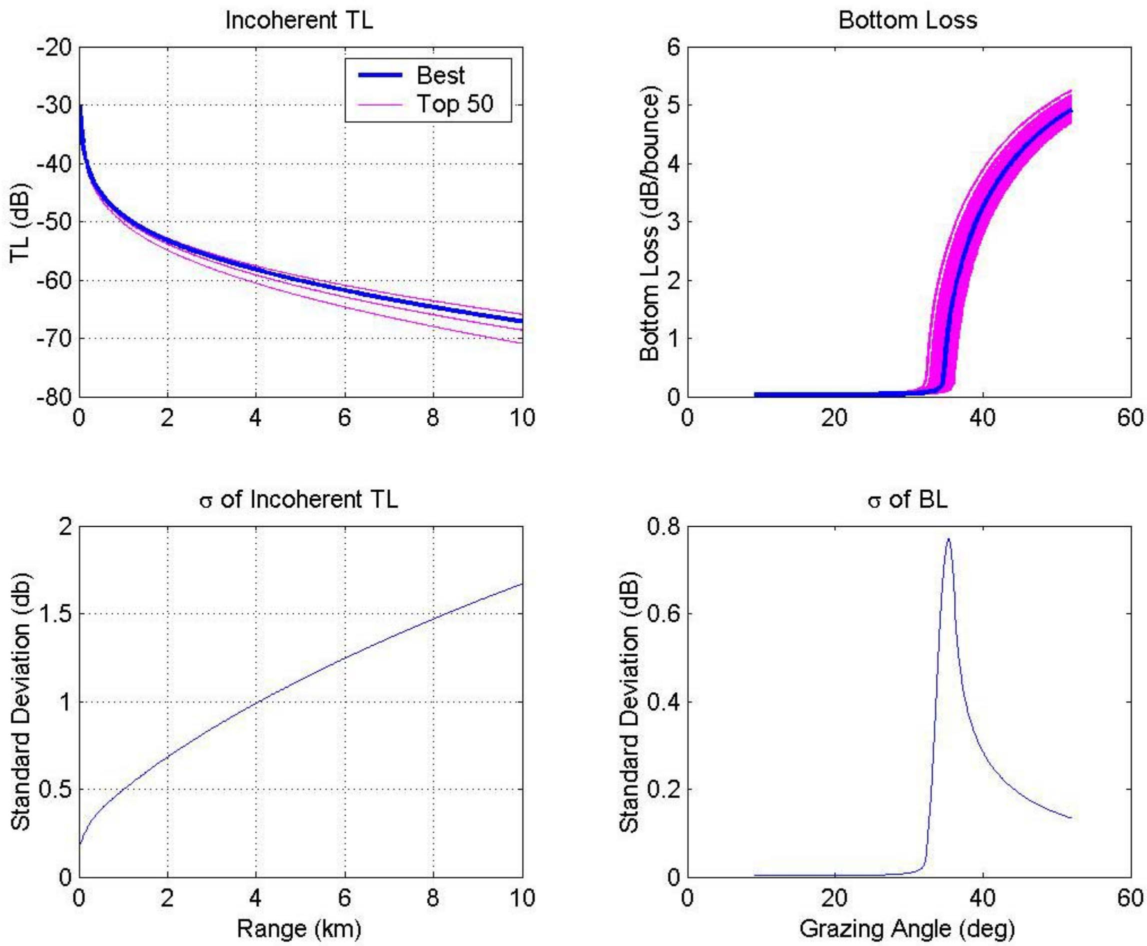

Figure 3. TL and Bottom Loss for the ensemble of sediment profiles within 5% of the best estimate. Standard Deviations of the TL and BL are shown in the lower panels.

We see from this profile that most of the incoherent TL's are very, very close to the best estimate. This indicates that a change in the geo-acoustic profile (mostly corresponding to a sediment depth change) will not effect the TL. The standard deviation of the TL is on the order of 1 dB at 4km range. The TL is therefore well estimated with this geo-acoustic profile. (Provided the data was good in the first place.) The bottom loss (BL) curves are informative in that they show that there is almost no variability in the low grazing angle bottom loss, but some uncertainty in the critical angle. The critical angle is well estimated to 36 degrees within a few degrees. The propagation at long ranges appears to be dominated by the low grazing angle reflection coefficient, which is well estimated.

To pass the uncertainty and sensitivity due to the local geo-acoustics through the system, the variability in TL is mapped to the variability in performance of an ASW system. Looking at the upper panel of Fig. 3, we see that for a FOM of 60 dB TL was required by the sonar equation, (FOM = SL – AN + AG) the detection range the estimated detection range would be 5km with an uncertainty of range between 4 and 6km. This level of transferring uncertainty, through simple sonar equation analysis, is effectively determining the slope of the TL vs. range curve and mapping it's inverse. Range of detection sensitivity is the inverse of the slope of the TL. The RGC inversion process estimates the

slope of the TL vs range parameter (α – the Effective Attenuation Parameter) and it is measured in dB/km. Given a 1-2 dB uncertainty (U) in prediction, the range uncertainty of a system is $\Delta R = U/\alpha$.

We are in the process of developing an analytic rule set based upon the sound speed profile, which will determine what environmental parameters are most important. For example in the above case, the geo-acoustic parameters were dominant. In an upward refracting environment, or in deep water, geo-acoustics is not important, possibly sound speed profile, internal waves or surface effects may be important.

IMPACT/APPLICATIONS

This expected impact of this project is to provide a methodology to provide a reliability measure to the operator of at-sea performance prediction models.

TRANSITIONS

Ideas, algorithms and approaches from this work are expected to transition in ’04 or ’05 to the ASTO APB (Advanced Processor Build) submarine sonar system program.

RELATED PROJECTS

This is one of the programs in the ONR UNCERTAINTY DRI.

PUBLICATIONS